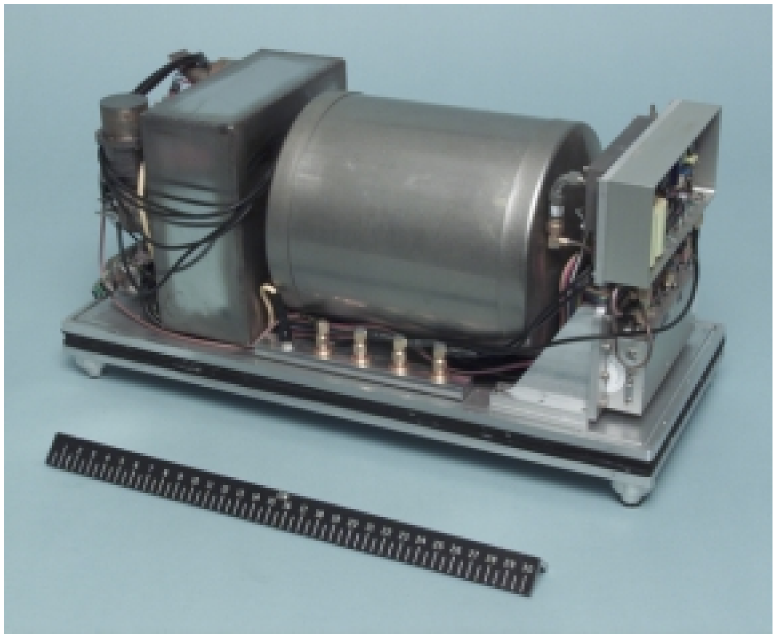
NRL Spacecraft Atomic Clock Technology



Spacecraft Atomic Clocks are one of the most critical aspects of the Global Positioning System (GPS).They provide the accurate, stable frequency reference that is the basis for GPS positioning, navigation, and timing. The excellent performance attained by the system has spurred new requirements for even better accuracy and reliability. Spacecraft Atomic Clocks will always be key components of the system. Today's success has been the result of dedicated efforts to design and build the best available satellite clocks.

The Naval Research Laboratory (NRL) is currently developing space clock technology for near-term possible use in the NAVSTAR GPS. The continued development of this spacecraft clock technology is a vital component to the capability for precise position and time information from satellites. The elements discussed below constitute the Clock Technology Roadmap as jointly developed by the GPS Joint Program Office (JPO) and the NRL. This effort includes clock technology development, test and evaluation of satellite precision timing systems and sub-systems, development of the means to validate in-orbit performance in the system and final transition to operational use. Four different technical approaches to precise atomic clocks for space are being examined for continued development. By adopting several approaches the program permits maintaining a spirit of competition to help ensure a more cost-effective approach.

The Spacecraft Atomic Clock technologies for spacecraft are:
Rubidium Atomic Frequency Standards with digital electronics,
Sub-Compact Hydrogen Maser Standards,
Optically Pumped Cesium Beam Standard, and
Linear Ion Trap Frequency Standards.

These technologies were selected for their maturity levels and possibly for near-term development of Flight Demonstration Models (FDM) that could be integrated for test in orbit with the Block IIF satellites now under development. Digital electronic designs for the technology are principal components of more robust and producible units for the system. Clock performance is a critical system performance parameter; however, new clocks need to have a more intelligent capability for monitoring, optimizing and providing the system operator with indications of good health and operating life.

Spacecraft clocks have had problems because the system operator was unable to adequately monitor, diagnose and maintain reliable clock operation. A large part of this problem is adequate telemetry and monitors to fully determine the state of the clock and possible problem areas. This effort includes development of advanced state-of-the-art Diagnostic, Prognostic and Testability techniques that would be incorporated into the spacecraft digital electronic designs. The digital designs will then be used to develop generic and technology specific evaluation schemes, diagnostics and prediction algorithms. Integrated instrumentation to measure and compensate for thermal, mechanical stress and operating parameter sensors would be used. These techniques would also provide a more testable unit during spacecraft assembly and ground test prior to launch. Potentially, the clock may be able to evaluate itself without considerable test support during these pre-launch stages. Correspondingly the techniques could be applied on-orbit providing the system operators with a more accurate and unambiguous evaluation of anomalies and routine operating conditions.

The specific technologies and efforts underway are to develop a FDM of these technologies for potential space flight in GPS satellites. These FDMs are to be designed for a limited duration evaluation to reduce the costs for fully qualified certified operational units. Prior to selection for integration and launch they will be evaluated for possible space flight in the NRL Precise Clock Evaluation Facility.

ADVANCED RUBIDIUM: NRL and a contract development effort is based on the units developed during earlier phases of the GPS program by Perkin-Elmer. An advanced version is being developed, incorporating improvements in the physics unit and digital electronics, for operation and spacecraft interfacing. These units will provide the foundation of high performance needed for GPS today and in the future.

SUB-COMPACT HYDROGEN MASER: NRL's existing hydrogen maser technology for GPS is being re-evaluated in view of today's performance expectations and evaluation of the new technologies. Design options have been reviewed and correlated to determine an optimum approach for the development of a subcompact maser for GPS spacecraft. The design for this device focuses on performance, size and power necessary and compatibility with a digital implementation of the electronics.

OPTICALLY PUMPED CESIUM CLOCK: This portion of the program is conducted under contract by Datum, Beverly. An optically pumped cesium standard has been attempted several times in the past for ground applications but not seriously for space, until recently. With Datum's initial investment in a laboratory unit the potential of developing a spacecraft became realized. Datum is producing conventional cesium units for the Block IIF operational clocks incorporating digital electronics from NRL's prior development effort for GPS. If the conventional tube could be replaced with a new beam tube that employs optical pumping techniques this would significantly improve performance. The key technology for this effort to succeed is the laser to be used and a special emphasis has been placed in that area.

SPACE LINEAR ION TRAP SYSTEM (LITS): The Jet Propulsion Laboratory Time and Frequency Group are working with NRL in developing this technology for space. Operational versions of these units have been being deployed in NASA's Deep Space Network as a potential replacement for the large hydrogen masers currently in use. A spacecraft version of these units has been investigated and offers the potential of very small size and power with potentially high stability. The physics package is small but since it is a passive device a high quality local oscillator is needed to gain the full potential of these devices. The potential performance gain using a modest performance local oscillator and the adaptability to digital implementation of the electronics could be a major step in spacecraft clocks.

SATELLITE ON-BOARD INTERCOMPARISON SUBSYSTEM (OIS): The operation of FDM units in GPS can be accomplished by using a special On-Board Comparison Subsystem that provides high precision comparisons with the operational On-Board Clock. A digital dual-mixer subsystem to inter-compare three or more clocks simultaneously, developed at NRL, will be used to evaluate these units in GPS spacecraft without jeopardizing the operational mission of the spacecraft. The final major developmental step is to verify the units produced by actual use in orbit. This spaceflight verification would validate performance within GPS system requirements. Several of these space-qualified units will be produced for potential integration of FDM into the GPS satellites.

By precisely comparing the FDM with the operational Spacecraft Atomic Clock and downlinking the data in the telemetry, a precise comparison of the FDM with ground references can be accomplished within the system without disruption to system operation. The OIS will provide a continuous record of performance, monitoring information for evaluation. Existing techniques for evaluating the performance of the operating clock within the system could provide traceability to the DoD Master Clock. This background operation could also provide an additional benefit by providing a continuous comparison with the operational clock in the situation where the operational clock exhibits anomalous behavior.

Should the background evaluation prove successful onboard a Block IIF spacecraft and with an additional clock input into the spacecraft transmitter, provided by Boeing, the option exists to use the test clock to drive the operational transmitter. The effect of the clock's performance in the operational system could then be fully evaluated.

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